The cost optimal methodology applied to an existing office in Italy

CRISTINA BECCHIO
TEBE Research Group, DENERG, Politecnico di Torino, Italy
cristina.becchio@polito.it

STEFANO P. CORGNATI
TEBE Research Group, DENERG, Politecnico di Torino, Italy

ENRICO FABRIZIO
TEBE Research Group, DISAFA, Università degli Studi di Torino, Italy

VALENTINA MONETTI
TEBE Research Group, DENERG, Politecnico di Torino, Italy

Summary

While new buildings should be designed as intelligent low or zero-energy buildings, refurbishment of existing building stock has many challenges and opportunities of saving because, in the building sector, most of the energy is consumed by existing buildings. Since the replacement rate of existing buildings by the new-build is only around 1–3% per annum, a rapid enhancement of taking up retrofit measures on a large scale is essential for a timely reduction in global energy use and promotion of environmental sustainability. Consequently, defining the most cost and energy effective retrofit measures for the existing buildings represents a key element in European energy policies. The cost optimal methodology can be used as a useful tool for this aim. The present paper reports the first outcomes of an application of this methodology to a reference building for an existing office customized to the Italian context. The Rehva Task Force "Reference Buildings for Energy and Cost Optimal Analysis" deals with this topic.

Introduction

The recast of the Directive on the Energy Performance of Buildings defined all new buildings will be nearly zero-energy buildings by the end of 2020. However, the transformation of the EU's building stock will not be completed until well after 2020 and this target can only constitute an intermediate step. The renovation of existing buildings stock offers significant potential for both cost-effective CO_2 emissions mitigation and substantial energy consumption reduction. Therefore energy efficiency can be seen as Europe's biggest energy resource. The cost optimal methodology may be a useful tool able to identify the more appropriate retrofit measures in order to launch the renovation of the existing building stock on a large scale [1].

Therefore, hereby the application of the cost optimal methodology to a reference building (RB) for existing offices customized to the Italian context is presented. The identification of the most suitable energy efficiency measures (EEMs) becomes a key element of national energy policies, in order to guide the possible introduction of specific subsidies or financial tools. Specifically, different EEMs involving the improvement of the building envelope thermal performances and the systems efficiency were considered. Moreover, the utilization of renewable energy sources was taken into account with the installation of a PV system on the building roof. Then, the energy consumptions of the RB and the impact of the improvement measures were assessed with a dynamic simulation software tool. Finally, the costs of the different packages were estimated, according to the European Standard EN 15459:2007, in order to establish which of them has the lowest global cost and, consequently, represents the cost optimal level.

The case study

The main purpose of a RB is to represent the typical and average building stock in a certain Member States, since it is impossible to calculate the cost optimal situation for every individual building [2]. Hence, it must be chosen to reflect as accurately as possible the present national building stock so that the methodology can deliver representative calculation results.

The case study hereby analyzed is a theoretical Reference Building that is a fictional building composed of disaggregated statistical data related to the main building features gathered together to create a typical Italian office building [3]. It is the results of a national survey carried out by ENEA (Italian National Agency for New Technologies Energy and Sustainable Economic Expansion) and finalized to a quantitative and qualitative analysis of the Italian office building stock [4]. The RB is representative of office buildings located in the North of Italy and built since 1970 until today.

The RB is a five-storey office building with an unconditioned basement and it is located in Turin and characterized by a total net conditioned area of 2 300 m^2. The gross area of a typical floor is equal to 480 m^2, while its gross height is equal to 3.5 m. The building has a rectangular plan (16 m x 30 m), with an interior layout characterized by cellular offices on the perimeter areas and a central core for the services areas. It is oriented N-S on its cross-section. It has an aspect ratio of 0.33 m^{-1}; it is thus a quite compact building. The ratio of the transparent area to the opaque envelope is 38%.

It consists of a reinforced concrete structure, brick walls with insulation (U = 0.75 W/m²K), plane insulated roof (U = 0.81 W/m²K) and double glazing windows with aluminum frame with thermal break (U = 3.19 W/m²K) and with internal blinds.

The primary system is constituted by a condensing boiler and a chiller with cooling tower; the terminals of heating and cooling system are four-pipe fan coil units.

The energy efficiency measures

The definition of the EEMs, that are all technically feasible, was carried out on two stages. The EEMs were aimed first to the improvement of the building envelope performances and then to the improvement of systems efficiency and to the exploitation of renewable energy sources. The latter measures were applied to some of the previous models, and in particular, to the RB, which is the solution with the lowest global cost, and to the model which reported the lowest primary energy consumption (EEM3).

The first set of 12 EEMs consists in an improvement of the thermal insulation of the building envelope; EEMs are distinguished into "homogenous measures" that regarded the whole building envelope or "not homogeneous measures" that concerned just selected building components. Since the RB is assumed to be located in Turin (climate zone E), the considered U-values correspond to the requirements established by the new regulations on energy performance of buildings in Piedmont Region [5]. Indeed the U-values applied for the EEM1 are the U-value limits set by the Piedmont Region regulation: (U_{wall} = 0.33 W/m²K; U_{roof} = 0.29 W/m²K; $U_{ground\ slab}$ = 0.30 W/m²K; U_{window} = 2 W/m²K); the U-values applied for the EEM2 are the optional U-value targets set by the Piedmont Regional regulation [5] (U_{wall} = 0.24 W/m²K; U_{roof} = 0.22 W/m²K; $U_{ground\ slab}$ = 0.26 W/m²K; U_{window} = 1.5 W/m²K); the U-values applied for the EEM3 are the optional U-value targets set by the Turin city regulation [6] (U_{wall} = 0.14 W/m²K; U_{roof} = 0.15 W/m²K; $U_{ground\ slab}$ = 0.16 W/m²K; U_{window} = 1.2 W/m²K).

In regard to the "not homogeneous measures", an improvement of the thermal insulation only of the windows is considered by EEM 4 (U_{window} = 2 W/m²K), EEM 7 (U_{window} = 1.5 W/m²K) and EEM10 (U_{window} = 1.2 W/m²K). An improvement of the thermal insulation of the roof and of the ground slab is evaluate by EEM 5 (U_{roof} = 0.29 W/m²K; $U_{ground\ slab}$ = 0.30 W/m²K), EEM 8 (U_{roof} = 0.22 W/m²K; $U_{ground\ slab}$ = 0.26 W/m²K) and EEM11 (U_{roof} = 0.15 W/m²K; $U_{ground\ slab}$ = 0.16 W/m²K).

Table 1. Description of Energy Efficiency Measures affecting the lighting system efficiency and the exploitation of renewable energy sources.

EEMs description		1st stage EEM	ID
Package 1	ALC[1]	RB[2]	EEM13[3]
		EEM3	EEM14
		EEM8	EEM15
Package 2	PV: 100% roof	RB	EEM16
Package 3	PV: 50% roof	RB	EEM17
Package 4	PV: 25% roof	RB	EEM18
Package 5	ALC PV: 100% roof	RB	EEM19
		EEM3	EEM20
Package 6	ALC PV: 50% roof	RB	EEM21
		EEM3	EEM22
Package 7	ALC PV: 25% roof	RB	EEM23
		EEM3	EEM24

[1]Artificial lighting control; [2]Reference building; [3]EEM xx= energy efficiency measure – see text

An improvement of the thermal insulation of the external walls and of the windows is considered by EEM 6 (U_{wall} = 0.33 W/m²K; U_{window} = 2 W/m²K), EEM 8 (U_{wall} = 0.24 W/m²K; U_{window} = 1.5 W/m²K) and EEM12 (U_{wall} = 0.14 W/m²K; U_{window} = 1.2 W/m²K).

The EEMs considered within the second stage consisted in the introduction of an artificial lighting control (ALC) and in the installation of PV panels on the plane roof. Three different configurations were studied for PV panels: covering of the entire, of one half and of one fourth of the roof (**Table 1**).

Calculation assumptions

The objective of the energy evaluation was to determine the annual overall energy use in term of delivered energy (divided by sources) and primary energy, which includes energy use for heating, cooling, lighting and equipment. The energy consumption of the RB and the impact of the improvement measures were assessed with the dynamic simulation software EnergyPlus.

Unlike other various studies that are being developed on this topic, this work is characterized by the use of dynamic simulation in order to accurately estimate the energy demand for heating, cooling, electric lighting, electricity from renewable sources, and especially the trade-off between heating energy and cooling energy, that is particularly important in an office building. Given the use of dynamic simulation and the inherent calculation times, a study based on a limited amount of technically feasible packages of energy efficiency measures, rather than a parametric study, was conducted.

Finally the calculation of the global cost of the RB and of the different packages of EEMs was developed in order to establish which of them has the lowest global cost and, consequently, represents the cost-optimal level. The evaluation was developed in a macro-economic perspective; carbon price were not taken into account. The calculation period was set equal to 30 years. According to the Guidelines [7] the discount rate was fixed equal to 4%. The investment costs of EEMs were evaluated by referring to the price list of the Piedmont Region of 2012 [8].With regard to the data on the duration of the system components and their maintenance cost the reference was made to Appendix A of EN 15459:2007 [9]. According to the European trends until 2030 [10], an annual increase in gas prices of 2.8% and in electricity prices of 2% was taken into account; the inflation rate was also considered and put equal to 2.17%. Subsidies related to renewable sources were considered [11].

Results and conclusions

In order to find the cost optimal level, the primary energy consumption was plotted versus the global cost (**Figure 1**). In the graph, in correspondence to the reference building a vertical line that represents the maximum primary energy consumption was drawn. The position of the EEMs that were studied permitted to draw the trend of dotted broken line that represents the cost curve, the minimum of which may be considered as the cost optimal level.

The analyzed energy efficiency measures allow savings from 6 to 97 kWh/m²y (primary energy) in absolute terms; in percentage terms, savings are between 4 and 58%. In particular, EEMs 8, 5 and 11 (characterized approximately by an energy consumption of 160 kWh/m²y and a global cost of 545 €/m²) allow to achieve the minimum energy savings that can be obtained with the analyzed efficiency actions; these measures considered different levels of roof and ground slab thermal insulation. Instead, the minimum value of consumption is achieved with the EEM20 (69 kWh/m²y and 614 €/m²), which combines the maximum level of thermal insulation of the whole envelope with the introduction of the artificial lighting control (ALC) and the installation of PV panels covering the entire roof.

With regard to the global cost, EEM1 and EEM13 represent respectively the uppermost (649 €/m²) and the lowest (499 €/m²) extreme points. EEM1 consists in a thermal insulation improvement of the whole building envelope according to the current Italian regional regulation; EEM13 doesn't deal with building envelope efficiency measures but consists in the installation of ALC on the reference building. The graph underlines that EEMs have both lower and higher global cost values compared to the RB. Global cost values higher than RB tend to be the ones of the envelope EEMs, because the investment costs for the different efficiency measures cannot be repaid by the economic savings associated with energy savings obtained. Global costs lower than the cost of the RB tend to be associated with EEMs concerning the systems because of their lower investment costs, as shown in **Figure 2**. Indeed, EEMs 13, 15, 21 and 23 have approximately the same value of global

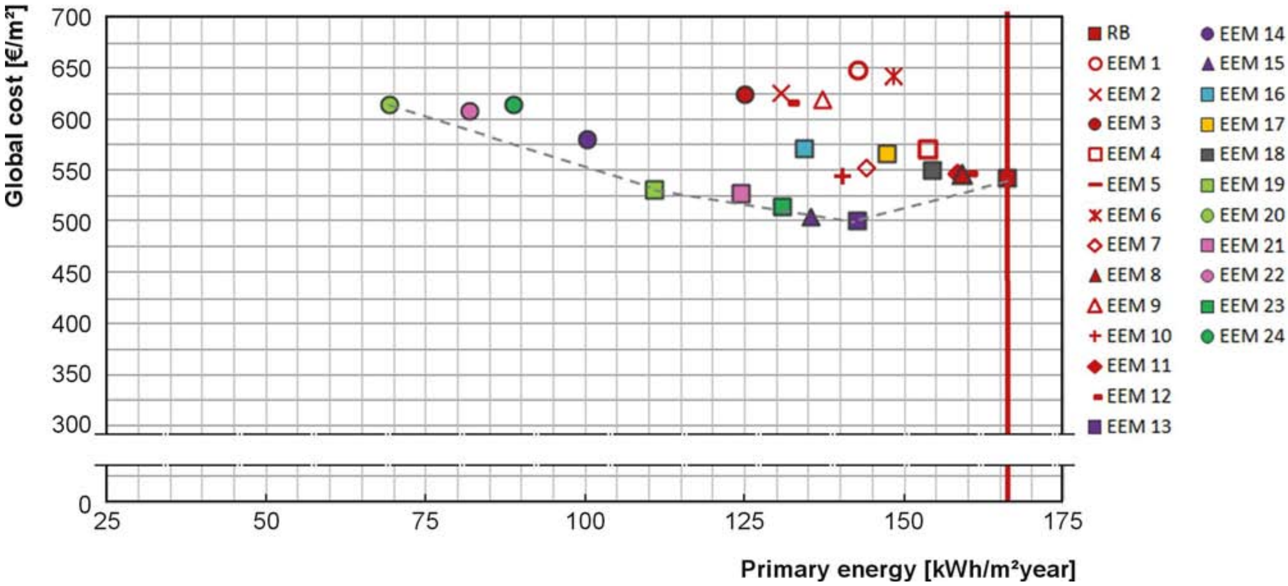

Figure 1. Global cost graph for the existing office.

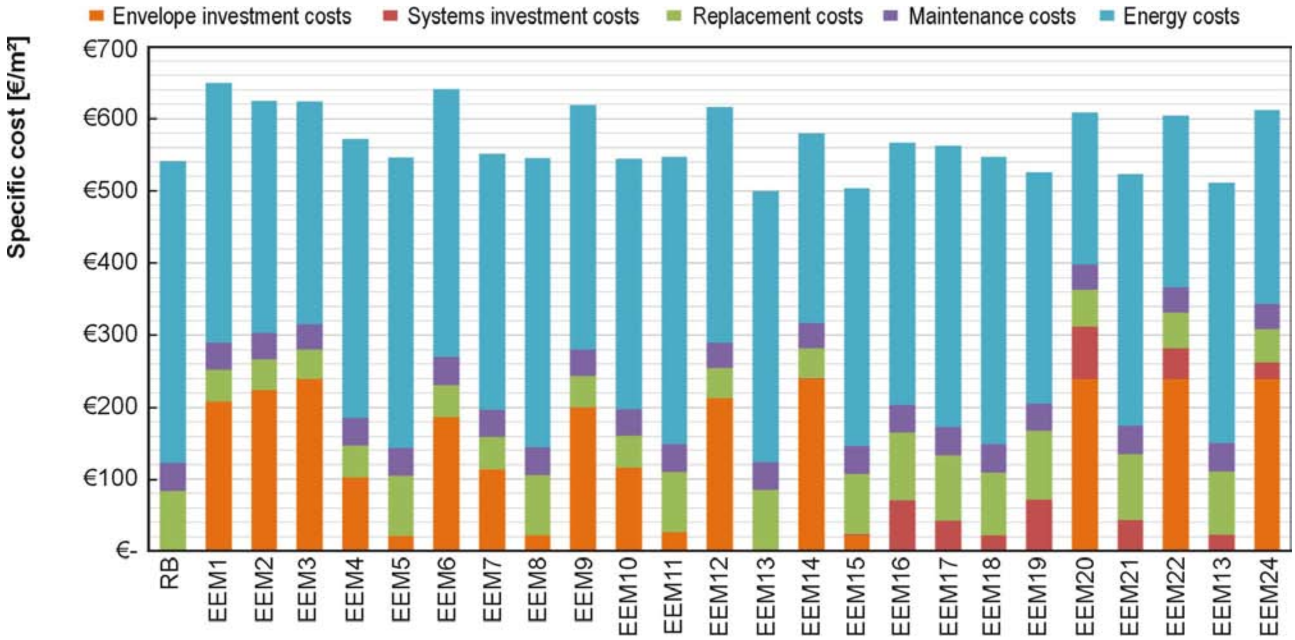

Figure 2. Costs breakdown analysis for Reference Building (RB) and different Energy Effciency Measures (EEMs) for the existing office.

cost, that ranges between 499 and 527 €/m². EEM15 consists in the improvement of roof and ground slab thermal insulation (according to the optional U-values targets set by Italian regional regulations) and in the introduction of ALC; while EEMs 21 and 23 are characterized by the installation of ALC and different PV system configurations. The EEM with the lowest global costs is EEM13 and has a primary energy consumption of 143 kWh/m²y. It does not improve the thermal insulation of the building envelope but considers only the introduction of ALC.

Further studies are needed to simulate different EEMs which combine various levels of thermal insulation for the envelope components (windows, walls, roof, slab) and EEMs related to the building system, and to carry on sensitive analyses on the discount rates and, in particular, on different developments of energy price. ■

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